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Mercury Availability—Market Economy Countries

A Minerals Availability Appraisal

By C. P. Mishra, D. R. Wilburn, D. G. Hartos, C. D. Sheng-Fogg, and R. C. Bowyer

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
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PREFACE

In order to assess the availability of strategic and critical nonfuel minerals, the Bureau of Mines Minerals Availability Program identifies, collects, compiles, and evaluates information on producing, developing, and explored deposits and mineral processing plants worldwide. Objectives are to classify domestic and foreign resources, to identify by cost evaluation resources that are reserves, and to prepare analyses of mineral availabilities.

This report is one of a continuing series of reports that analyze the availability of minerals from domestic and foreign sources. Questions about the Minerals Availability Program should be addressed to Chief, Division of Minerals Availability, Bureau of Mines, 2401 E Street NW., Washington, DC 20241.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	mg	milligram
cm	centimeter	mg/L	milligram per liter
h	hour	mg/m^3	milligram per cubic meter
km	kilometer	µg	microgram
L	liter	$\mu g/m^3$	microgram per cubic meter
lb	pound	mt	metric ton
m	meter	pct	percent
m^3	cubic meter	yr	year

MERCURY AVAILABILITY—MARKET ECONOMY COUNTRIES

A Minerals Availability Appraisal

By C. P. Mishra,[1] D. R. Wilburn,[2] D. G. Hartos,[3]
C. D. Sheng-Fogg,[2] and R. C. Bowyer[4]

ABSTRACT

The Bureau of Mines investigated the availability of mercury from 22 deposits in market economy countries. The 15 significant deposits evaluated have demonstrated resources of approximately 25 million metric tons of ore containing 5.3 million flasks of mercury and account for more than 85 pct of the demonstrated resources for market economy countries. Using data gathered as part of its Minerals Availability Program, the Bureau determined the mercury production potential of each deposit.

At a January 1984 mercury market price of $300 per flask, the deposits evaluated could economically produce an estimated 2.5 million flasks of mercury from six mines operating at the time of this study; no mercury is available at this price from nonproducing operations. At $600 per flask, approximately 4.5 million flasks of mercury are available. For production costs up to $300 per flask, operating mines could supply mercury at the current production rate of 114,000 flasks per year until 1988, when the amount of mercury available from these deposits would decrease. This decline could be offset by the development of resources currently reported at the identified level (17 million flasks) at much higher production costs.

[1]Supervisory physical scientist.
[2]Physical scientist.
[3]Physical scientist (now with Office of Surface Mining, Pittsburgh, PA).
[4]Geologist.
Minerals Availability Field Office, Bureau of Mines, Denver, Co.

INTRODUCTION

Mercury's unusual combination of physical and chemical properties gives it an industrial and economic importance much greater than the size of its production would indicate. It is considered by the Bureau of Mines to be a critical commodity for the United States owing to its extensive use in a variety of industrial, scientific, and military applications, many of which have few satisfactory substitutes. Despite its importance, significant production is geologically restricted to a limited number of areas, many of which have ceased production in recent years as a result of depressed market conditions.

Production in the United States, Yugoslavia, and Italy has declined sharply, while mercury mines in the U.S.S.R. and China have achieved a greater degree of world prominence. In 1983, the United States produced 50 pct of its consumption from primary sources of mercury and 28 pct from secondary sources. The remaining 22 pct was imported or supplied from Government stockpiles, *(12)*.[5] Most of the current domestic production comes from one mine which has an expected life of 5 to 8 yr.

Owing to the critical nature of mercury and its limited sources of supply, it is important to examine the availability of mercury from both present and potential sources. The Bureau's primary objectives for this study were to evaluate the availability of mercury from market economy countries[6] and to assess domestic mercury resources in relation to those of other market economy countries. These availability determinations can be used in the development or modification of a domestic minerals policy and can be of direct benefit to programs concerned with mineral stockpile assessment, minerals exploration, extraction technology research, tax restructing, substitute mineral studies, and land utilization. No comprehensive world mercury resource studies have been conducted since the late 1950's, and no recent comprehensive availability studies on mercury have been published. This study consolidates past work *(9, 11)* with more recent data from numerous sources and summarizes available industry data on mercury as of January 1984. Current and potential availability data for mercury are presented in a series of supply curves with appropriate explanatory text.

ACKNOWLEDGMENTS

Domestic production and cost data for the deposits assessed in this study were developed at Bureau of Mines Field Operations Centers at Denver, CO, and Spokane, WA. The following personnel contributed data used in this study: Alan G. Hite, physical scientist, Intermountain Field Operations Center, Denver, CO, and David A. Benjamin, George A. Gale, Nathan T. Lowe, Michael Sokaski, and Thomas M. Sweeney, all at the Western Field Operations Center, Spokane, WA.

Production and cost data for other countries were collected through a Bureau of Mines contract with Pincock, Allen, & Holt, Inc. of Tucson, AZ. Selected resource and production data were provided by Linda Carrico, Bureau of Mines commodity specialist, Washington, DC. Technical assistance was provided by Victor Botts, manager, Nevada Operations, Placer U.S., Inc.

COMMODITY OVERVIEW

CONSUMPTION AND USES

Mercury, also known as quicksilver, is one of the few metals that is liquid at ordinary temperatures. Other important properties that influence its marketability include its high density, uniform volume expansion, high electrical conductivity, ability to alloy readily, high surface tension, chemical stability, and toxicity of its compounds.

Mercury's unique characteristics have enabled it to be used historically in a wide variety of applications, including electrical apparatus, industrial and control instrumentation, agriculture, pharmaceuticals, paints, pigments, electrolytic preparation of chlorine and caustic soda, and dental supplies. Owing to the toxic nature of mercury vapor and certain compounds, its use in some of these areas has been restricted in recent years. Since world mercury use patterns are not available, the domestic uses of mercury are outlined in figure 1.

Worldwide consumption data by end use are not available. However, it is estimated that approximately 220,000 flasks of mercury were consumed in 1983 *(2)*. Demand will most likely increase more rapidly in developing countries than in industrialized nations. Based upon anticipated growth in world mercury consumption, the forecasted world demand in 2000 is estimated to be between 212,000 and 356,000 flasks. The most probable demand is 241,000 flasks in 1990 and 276,000 flasks in 2000, based on an average annual growth rate of 1.4 pct *(2)*. This growth rate is based on best available published data; recent data indicates that the growth rate may in fact be lower. A summary of anticipated mercury demand is presented in table 1.

SUBSTITUTES

Other materials may be substituted for mercury in selected application, but for those uses that require mercury's unusual combination of physical and chemical properties, there have been few satisfactory substitutes. Nickel-cadmium batteries may replace mercury batteries in cer-

[5]Italicized numbers in parentheses refer to items in the list of references preceding the appendix.

[6]Market economy countries, as defined by the Bureau of Mines include all countries except the centrally planned economy countries of Albania, Bulgaria, China, Cuba, Czechoslovakia, the German Democratic Republic, Hungary, Kampuchea, North Korea, Laos, Mongolia, Poland, Romania, the U.S.S.R., and Vietnam.

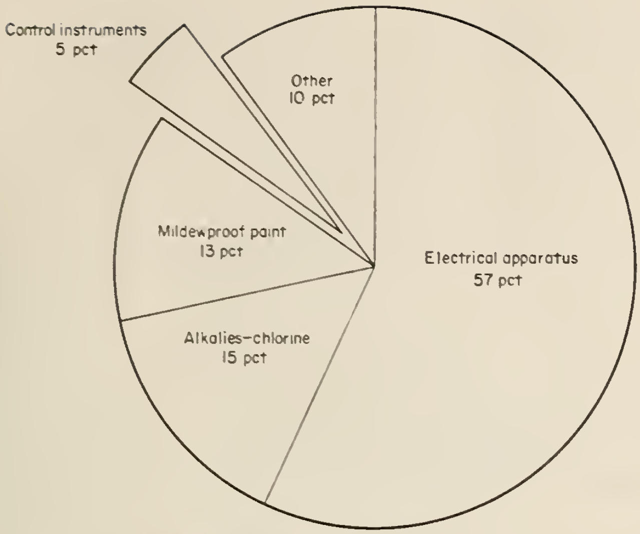

Figure 1.—Mercury use distribution.

Table 1.—Summary of domestic and foreign mercury demand forecasts, 76-pound flasks (*2*)

	1983	Probable 1990	Probable 2000	2000 Low	2000 High
Domestic:					
Primary	35,664	42,000	39,000	14,000	64,000
Secondary	13,474	6,000	7,000	3,000	12,000
Foreign:					
Primary	152,000	170,000	200,000	164,000	236,000
Secondary	19,000	23,000	30,000	31,000	44,000
World:					
Primary	187,664	212,000	239,000	178,000	300,000
Secondary	32,474	29,000	37,000	34,000	56,000
Total	220,138	241,000	276,000	212,000	356,000

tain electrical applications. Solid state control devices can replace mercury in some control instrumentation. In chlor-alkali processing, the diaphragm cell is gradually replacing the mercury cell. Sodium vapor lamps are widely used instead of mercury vapor lamps for lighting. Sulfa drugs, iodine, other antiseptics and disinfectants are possible mercury substitutes in pharmaceutical use. Porcelain and plastic replace mercury in some dental uses. Plastic and copper oxide paints have been used to protect ship hulls, and organic mildewcides are being substituted in latex paints.

RECYCLING

Environmental concerns have led to increased use of recycling of scrap mercury at the expense of prime virgin material. Secondary mercury is generally 99.99 pct pure and produced by redistillation. Virtually all mercury can be reclaimed from mercury cell-chlor-alkali plants, electrical apparatus, and control instruments when plants or equipment are dismantled or scrapped. Reduced demand for chlorine has closed a number of chlor-alkali plants worldwide; conversion of these plants to other processes has recently released a significant quantity of secondary mercury on the market. The importance of recycled mercury is illustrated by current domestic consumption patterns, where secondary mercury accounted for 28 pct of the reported domestic consumption in 1983 (*12*).

PRODUCTION HISTORY

For more than 2,300 yr, mercury has been recovered from cinnabar (HgS) deposits throughout the world. While mercury is found in varying amounts in most rocks, recoverable concentrations of mercury are more scarce. Prior to 1850, three mining districts dominated world mercury production: Almaden in Spain, Idria in Yugoslavia, and Santa Bárbara in Peru. Four major districts, Monte Amiata in Italy, California in the United States, Almaden, and Idria, have supplied most of the world's mercury production since 1850.

The Almaden area has produced mercury since 400 B.C. Records dating back to 1500 show production of over 7 million flasks of mercury through 1957 from Almaden (*9*), or almost three times as much as that of any other area of the world. Currently, about 23 pct of world production comes from the Almaden district.

Mercury in the Idria district of Yugoslavia was first discovered about 1470. Since then, the Idria Mine has produced over 2.5 million flasks of mercury through 1957 and ranked second in the world for total mercury production. The Idria Mine was closed from 1977 to 1982 owing to a depressed market.

The Santa Bárbara district, which included the Santa Bárbara Mine in Peru, was for many years the world's leading mercury producer. From 1566 to 1790, this district produced 1.47 million flasks of mercury. By the end of the 18th century, reserves were almost depleted; since then only negligible amounts of mercury have been produced. In terms of total output, Santa Bárbara has been ranked as the fourth largest mercury mine in the world (*9*).

Almost all Italian mercury production came from the Monte Amiata district. While mercury occurrences in this area were known and mined by the Etruscans as long ago as 400 B.C., modern production did not start until 1868. The extent of the mineralization was such that as reserves in individual mines were depleted, other mines in adjacent areas opened up for production. Italy led the world in mercury production in the 1920's, when the Idria Mine was part of Italian territory. Between 1900 and 1957, Italian mercury production from the Monte Amiata district exceeded 2 million flasks. The Abbadia San Salvatore Mine, the northernmost producing mine in the district, was the largest and most consistent producer in Italy in recent years, until its closure in 1982 due to economic factors.

Production of mercury in the United States began in California about 1850. California mines produced about 80 pct of the total mercury mined in the United States from 1850 to 1981, and almost all of the domestic mercury mined from 1850 to 1898.

Much of California's mercury production came from two mines, the New Almaden Mine and New Idria Mine. The New Almaden Mine was the first mine in North America to produce mercury; more than 90 pct of its production occurred between 1850 and 1900. Earliest production came from ore averaging 37 pct Hg. At the height of production in 1865, ore grade had dropped to 18 pct, and by 1895 the grade was less than 1 pct. During its life, New Almaden produced over 1.05 million flasks of mercury (*11*). The New Idria Mine opened in 1853, but unlike New Almaden, two-thirds of its production occurred after 1900. The New Idria Mine produced over 600,000 flasks of mercury until its closure in 1972 (*1*).

In recent years, declining ore grade, low prices, and lack of demand have forced the closure of all California mercury

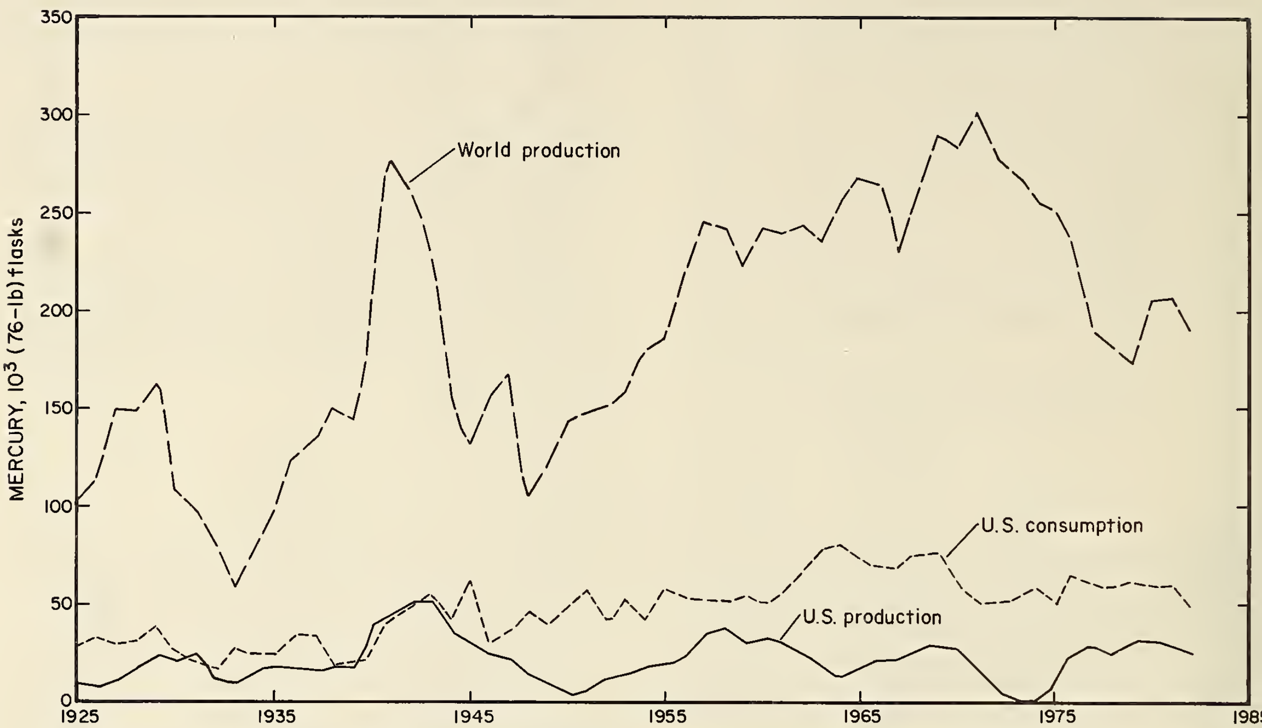

Figure 2.—Summary of production and consumption of mercury.

mines. Domestic mercury needs have been partially met by the opening in 1975 of the McDermitt Mine in Nevada.

Figure 2 summarizes the recent history of world mercury production. Domestic production and consumption for the same period are shown for comparison purposes.

Mercury production reached a high during World War II, but while world production managed to recover from the postwar decline in production, U.S. production never fully recovered. As shown in figure 2, the United States supplied approximately 14 pct of world production in 1960; by 1970, U.S. production had fallen to 10 pct of the world's total. Declining ore grade and high production costs, particularly for California operations, never allowed domestic production to meet the growing U.S. demand. In 1960, U.S. production met 71 pct of domestic consumption; by 1970, domestic production was only able to meet 44 pct of consumption. Because of increasing awareness of mercury toxicity, pollution, and use of substitutes since 1970, world mercury demand has decreased. U.S. production also dipped in the early 1970's because of increased environmental concern but stabilized in the mid-1970's owing to the emergence of the McDermitt Mine. At present, U.S. mine production is approximately 13 pct of the world mine production and supplies 50 pct of domestic consumption. The remainder is either imported or supplied by secondary domestic sources.

While low mercury prices, increased energy and labor costs, and environmental problems have forced the reduction or cessation of mercury production from market economy counties, mines in centrally planned economy (CPE) countries have achieved world prominence in recent years. Production in CPE countries was 20 pct of the world total in 1960, 25 pct in 1970, and 43 pct in 1980. In 1983, production from CPE countries amounted to 46 pct of world production of mercury.

MARKET AND PRICING HISTORY

The product of most mercury mines is cinnabar, which is commonly processed to recover 99.9-pct-pure mercury metal (prime virgin). Mercury is sold on the basis of 76-lb flasks. This unit of measure originated in Spain and has been accepted as a worldwide standard since Spain has been the world's leading mercury producer for centuries.

There are no uniform market specifications for mercury (*6*). The average New York dealers' price for prime virgin mercury as of January 1984 was $304.48 per flask. Other grades are produced occasionally by multiple distillation or other means to reduce impurities, at a correspondingly higher market price.

Mercury price has fluctuated widely because of erratic demand and overproduction. Domestic prices have also been influenced by environmental regulations, increased recycling, and imports from large, low-cost foreign producers. A

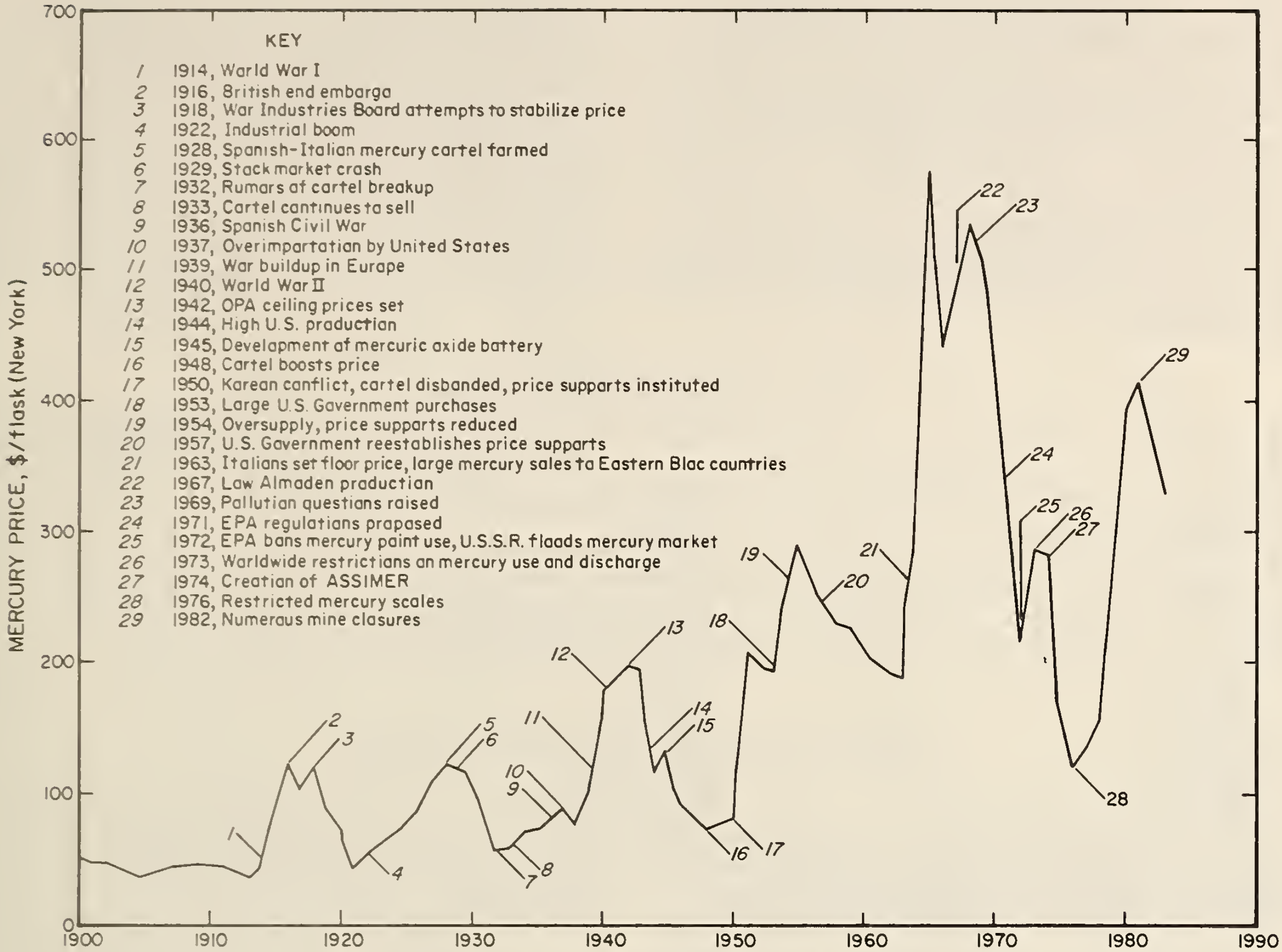

Figure 3.—Mercury market price history, 1900 to present.

summary of the mercury price history since 1900 is shown in figure 3.

In the early 20th century, mercury demand was highest during periods of peak industrial activity. Prices were high during World War I, the 1920's industrial boom, and World War II, but when demand decreased, as in the postwar years, mercury prices decreased dramatically. By 1950, the price of mercury has decreased to its lowest level since the Depression. At that time, prices were bolstered by increased industrialization resulting from the Korean conflict and price supports instituted by the U.S. Government. During the mid-1960's, the mercury price rose to an all-time high of $570 per flask, owing in part to Italian price regulation and large mercury demand by Eastern Bloc countries. Prices in the early 1970's were influenced by weak U.S. demand, increased environmental regulation, and large Spanish and Italian inventories. Low prices and high mining and environmental pollution control costs led to the closure of many low-grade domestic and Canadian properties. The withholding of mercury by Spanish and Italian producers from North American markets coincided with the 1976 price reversal. Because of tighter market controls as a result of the policies of the newly created mercury producers association, ASSIMER, mercury prices have gradually risen in recent years to a January 1984 price of approximately $300 per flask. In spite of this improvement, environmental concerns continue to dampen growth in domestic consumption, especially in paints, agriculture, pharmaceuticals, and the chlor-alkali industry (*12*). A combination of low prices, insufficient demand, large inventories, and high production costs suspended mercury production at the Italian mercury mines in 1983. At present, the McDermitt Mine is the only primary U.S. mercury producer.

IDENTIFICATION AND SELECTION OF DEPOSITS

There are over 1,300 known mercury occurrences throughout the world, and many more areas with possible mercury content (*9*). It is not feasible to perform complete economic analyses on all known occurrences. Of the 22 deposits investigated in this study, the 15 deposits with the most significant resource potential have been evaluated. Depositis considered for economic evaluation have at least 600 flasks contained mercury. Properties were selected by the Bureau with the aim of including key deposits that supply at least 85 pct of current production from market economy countries. Significant developing, explored, and past producing deposits were also included. Domestic deposits considered for evaluation, but not included in this study because they did not meet the selection criteria, are listed in appendix A. The 15 mercury deposits (table 2) in 7 market economy countries selected for this study account for more than 85 pct of the demonstrated mercury resources for all market economy countries. Figure 4 shows the locations of these deposits. Deposits in market economy countries not included in this study are considered insignificant on a worldwide scale. An exception would be the Idria Mine in Yugoslavia, which was excluded due to the inaccessibility of detailed data.

Resource estimates were made at the demonstrated level according to the mineral resource classification system developed by the U.S. Geological Survey and the Bureau of Mines (fig. 5) (*13*). Using this classification system, demonstrated resources are defined as the in situ measured plus indicated tonnages that make up the reserve base. Resource quantity and grade were determined from site inspections, drilling data, mine workings, and sampling. The reserve base includes resources that are currently economic (reserves) and marginally economic (marginal reserves), and some that are currently subeconomic (subeconomic resources).

Table 2.—Deposits selected for evaluation

Deposit and location	Ownership	Status[1]	Mining type[2]
Algeria:			
Ismail	SONAREM (Government owned)	P	S
M'Rasma	..do	P	S
Canada: Pinchi Lake	COMINCO, Ltd	N	S-U
Italy:			
Abbadia S. Salvatore	SAMIM (Government owned)	N	U
Selvena	..do	N	U
Philippines: Palawan Quicksilver	Palawan Quicksilver Mines, Inc.	N	S
Spain: Almaden	Arrayanes, S.A. (Government owned)	P	S-U
Turkey:			
Halikoy	Etibank (Government owned)	P[3]	U
Karaburun-Izmir	Undetermined[4]	N	S
Karareis	..do	N	U
Konya Area	Etibank (Government owned)	P[3]	U
United States:			
B and B Mine	Private individual	N	S
Gibraltar	Undetermined[4]	N	U
McDermitt	Placer U.S., Inc.	P	S
Study Butte	Sanger Investment Co.	N	U

[1]N = not producing as of January 1984; P = producing as of January 1984.
[2]S = surface; U = underground; for deposits not producing, mining type is proposed based on past history, geology, and technology.
[3]Operations producing at limited rate for internal use only.
[4]Ownership undetermined since property either has been abandoned or is involved in litigation.

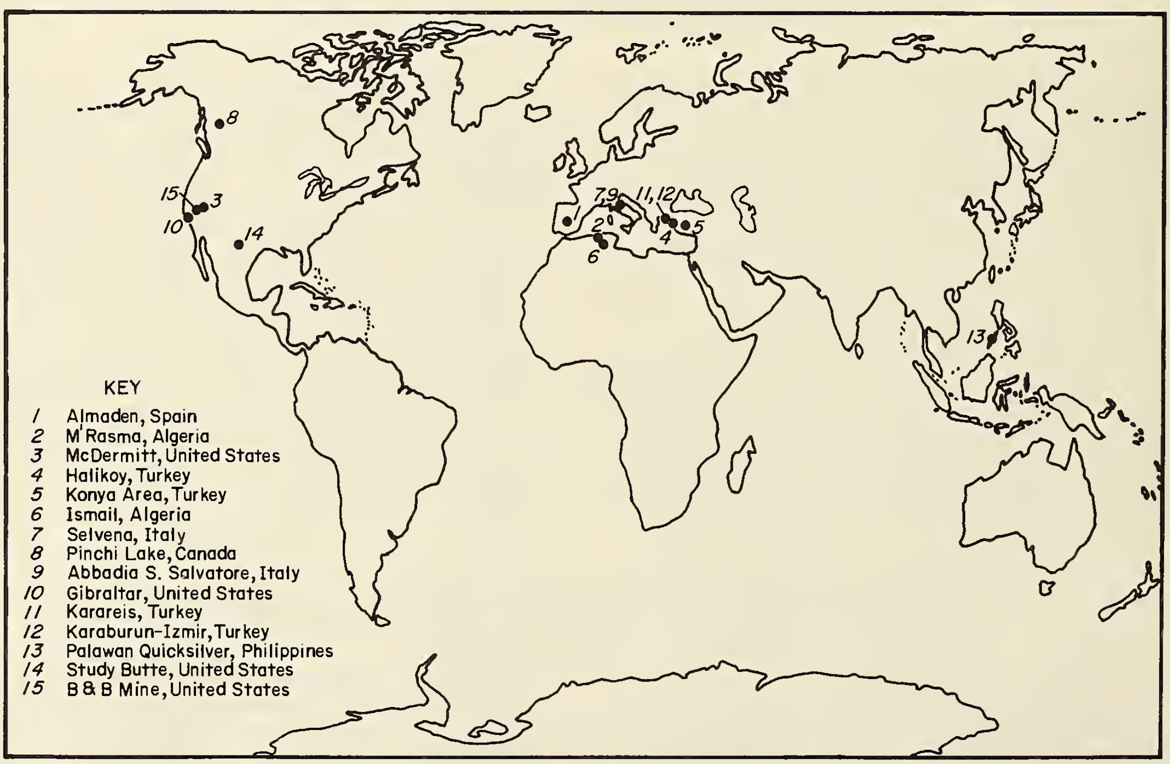

Figure 4.—Location map of evaluated deposits.

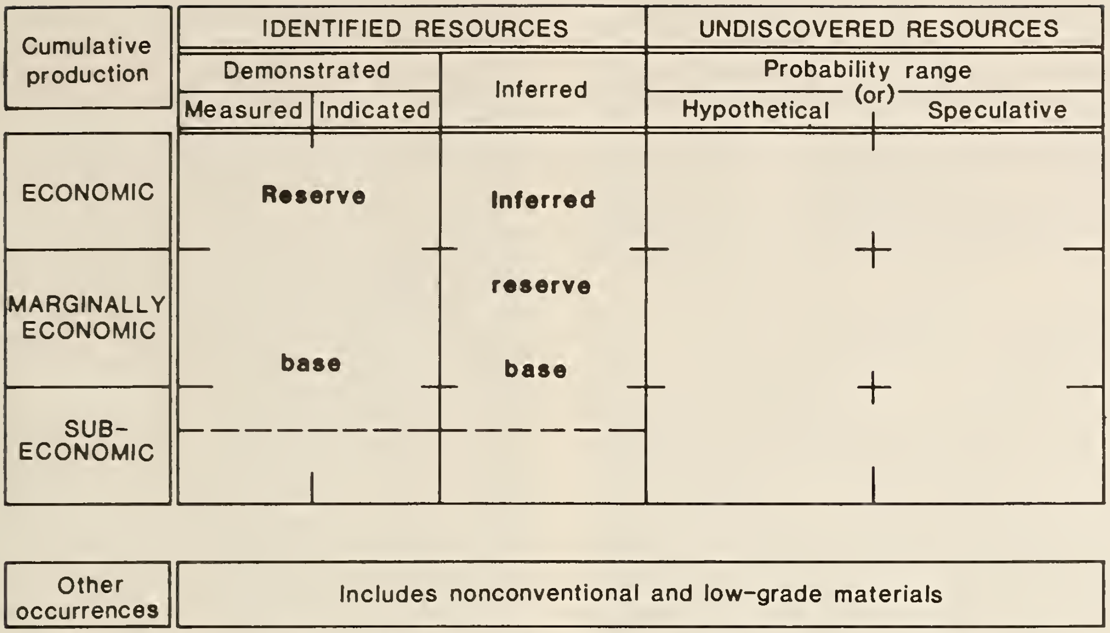

Figure 5.—Bureau of Mines—U.S. Geological Survey system for classification of mineral resources.

DEPOSIT EVALUATION PROCEDURES

Figure 6 is a flowsheet of the Bureau's Minerals Availability Program (MAP) evaluation process, from deposit identification to the development of availability curves. The flowsheet shows the various evaluation stages used in this study to assess the availability of mercury from individual domestic and foreign properties.

An outline of the methodology employed in this study follows:

1. The quantity and quality of world mercury resources were evaluated in relation to physical, technological, and other factors that affect production for each of the deposits

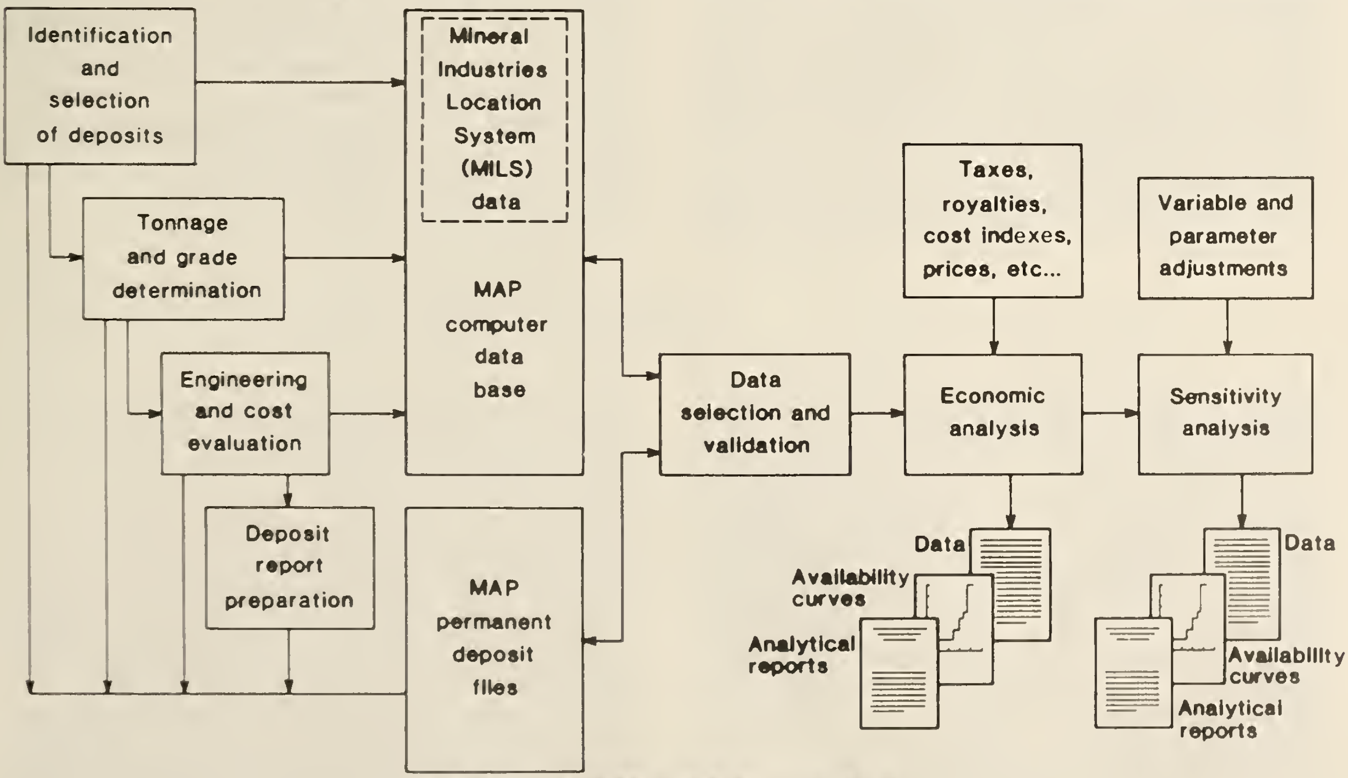

Figure 6.—Flowsheet of evaluation procedure.

evaluated. Only primary mercury sources containing at least 600 flasks of mercury were considered.

2. Capital and operating costs for appoprate mining, concentrating, and processing methods were estimated for each deposit.

3. An economic analysis was performed for each deposit to determine the total unit production cost.

4. Individual deposit cost-production relationships were aggregated and presented as total and annual availability curves to show production potentials at various production costs.

5. Sensitivity analyses on the effect of inflation, energy, and labor costs were also perfomed.

After a deposit was selected for analysis, a comprehensive evaluation of the property was performed. Domestic properties were evaluated by personnel at the Bureau's Field Operations Centers in Denver, CO, and Spokane, WA. Foreign properties were evaluated by personnel of the Minerals Availability Field Office in Denver, CO, from data collected by contractors. The designed mining and milling capacities were used for producing properties. For deposits not in production, mining, concentrating, smelting, refining, and transportation methods and production parameters were chosen based on applicable engineering principles, available deposit data, and current technology.

When possible, actual company cost data were used. If these data were not available, capital and operating costs were estimated. A costing system developed for the Bureau (*2*) was used for some domestic deposits. Use of this costing system produces estimates that historically have fallen within 25 pct of actual costs.

Capital expenditures were estimated for exploration, development, and mine and mill plant and equipment which include costs for mobile and stationary equipment, construction, engineering, support facilities and utilities (infrastructure), and working capital. Infrastructure includes all necessary costs for access roads, water facilities, power supply, port facilities, and personnel accommodations. Working capital is a revolving cash fund for operating expenses such as labor, supplies, taxes, and insurance. A working capital based on 2 months or 60 days of operating cost was used in evaluations.

All capital investments incurred prior to 15 yr of the study date (January 1984) were assumed to be fully depreciated or written off. Capital costs incurred less than 15 yr before 1984 were reported in dollar values of the year incurred; however, these costs were adjusted to reflect the remaining book value of the investment as of January 1984. All capital investments subsequent to January 1984 were reported in constant January 1984 dollars.

Mine and mill operating costs were developed for each deposit. The total operating cost is the sum of the direct and indirect costs. Direct operating costs include production and maintenance labor, materials, payroll overhead, and utilities. Indirect operating costs include administrative costs, facilities maintenance and supplies, and research and development. Costs not included in operating costs but used in the analyses include fixed charges, including transportation costs, taxes, insurance, depreciation, deferred expenses, and royalties.

After capital and operating costs were determined, data were entered into the Supply Analysis Model (SAM) (*4*). The Bureau developed SAM to perform an economic analysis which either presents the results as the primary commodity price (total production cost) needed to provide a stipulated rate of return or, for a given price, generates a rate of return on investment. The rate of return used in this study is the discounted cash flow rate of return (DCFROR), most commonly defined as the rate of return that makes the present worth of cash flows from an investment equal to the present worth of all after-tax investment. For this study, a 15-pct rate of return was considered necessary to cover the opportunity cost of capital plus risk. For some Government-owned operations, rate of return (profit) may not be required for continued production. However, for comparison purposes, each deposit was analyzed at a 15-pct rate of return.

Detailed cash-flow analyses were generated for each deposit under consideration. After each deposit's total cost of production was determined, individual deposit tonnages were aggregated at increasing production costs to determine mercury availability from all deposits evaluated. The results of these analyses are presented as availability curves discussed later in this report.

Sensitivity analyses were performed to determine the effects of inflation and increasing labor and energy costs on the availability of mercury. Separate analyses were made for producing and nonproducing properties.

GEOLOGY

Traces of mercury can be found in most natural substances. Mercury is recovered primarily as the red sulfide mineral cinnabar (HgS). Native mercury metal, metacinnabar, livingstonite, corderoite, and other mercury minerals are present in some ores but rarely in sufficient quantity to be recoverable. Principal gangue minerals include silica, feldspar, and carbonate minerals, with pyrite, marcasite, serpentine, and stibnite present in some localities. Valuable metals such as gold and silver are generally present only in trace amounts, although mercury has been recovered as a byproduct of gold and silver mining. All major producing districts recover mercury with no significant byproducts.

Mercury can be found in a wide variety of host rocks. Common host rocks include limestone, calcareous shale, sandstone, serpentine, chert, andesite, basalt, and rhyolite. Significant mercury deposits are found chiefly in regions of extensive Tertiary or Quarternary volcanic and tectonic activity in areas with a high degree of faulting or fracturing. Deposits are classed as epithermal, formed by the deposition of ore minerals from aqueous solutions at relatively low temperatures and shallow depths (*5*). The bulk of mercury ore mined has been from depths less than 300 m, although a maximum mining depth of 730 m has been achieved in California. For most deposits, the highest grade of ore is generally found in ore-bearing levels closest to the surface. Ore has been concentrated by replacement, open-space filling, and detrital concentration (*1*).

Mercury ore bodies are commonly small, irregular, and erratic (*5*). Three common forms are distinct veins of very high-grade cinnabar, disseminated ore occurring in fine-grained or brecciated ore zones, or disseminated ore along highly fractured contact zones. Higher grade disseminated ore is usually associated with open-textured rock types such as sandstone or coarse breccia (*6*). Lateral extent of ore zones is highly variable; generally, individual ore zone dimensions do not exceed 100 m. Vein thickness ranges from less than 1 to 21 m. The following brief descriptions of some principal deposits illustrate the diversity of occurrence that characterizes mercury deposits.

The Almaden district of Spain, historically the greatest producer of mercury, illustrates ore that occurs in highly concentrated bodies distinct from the surrounding host rock. The Mina Antigua ore occurs within three distinct quartzite veins enclosed in folded, faulted metasedimentary rocks of Silurian-Devonian age. El Entredicho ore consists of two distinct high-grade quartzite veins separated by a zone of carboniferous quartzite containing disseminated cinnabar. Ore in the Las Cuevas area of Almaden occurs as replacement of volcanics, rather than quartzite.

The Abbadia S. Salvatore Mine of the Monte Amiata district in Italy is an example of ore that has been disseminated throughout fine-grained or highly brecciated rock. Detrital cinnabar has been concentrated in highly fractured solution caves of Eocene limestone and shale. Dissemination of ore depends upon the extent of fracturing of the ore zones; consequently, mineralization and ore grade are erratic and variable.

Another type of disseminated ore is exemplified by the Turkish mercury deposits. Ore at the Halikoy Mine occurs in a highly fractured contact zone between mica schist and granitic gneiss. In the Konya area, ore occurs along a limestone-phyllite contact in areas where the host rocks have been folded and fractured. Cinnabar is erratically distributed as disseminations, clusters, and discontinuous veinlets.

In the Opalite district of Nevada, the location of the McDermitt Mine, ore occurs as lenses and irregular beds within argillized tuffaceous Miocene lakebeds and brecciated areas of the silicified lakebed sediments within 45 m of the surface (*6*). Unlike other deposits, ore occurs as both cinnabar and the mineral corderoite ($Hg_3S_2Cl_2$). The corderoite decreases in quantity with depth.

Mercury deposits in California have traditionally produced significant quantities of mercury, but are no longer producing. In this region, ore occcurs in silica-carbonate rock derived from hydrothermally altered serpentine (*5*). Cinnabar is found where the silica-carbonate has been replaced along steep fracture zones extending to depths up to 730 m.

RESOURCES

Demonstrated resources for 15 deposits evaluated in this study have been estimated at 25 million mt of in situ ore at a weighted average grade of 0.74 pct Hg. This ore contains an estimated 5.3 million flasks of mercury, of which 4.6 million flasks, or 87 pct, is recoverable utilizing current technology. Table 3 gives the demonstrated mercury resources as of January 1984 for evaluated market economy countries. Because of the sensitivity of mercury resource information in some countries, detailed information for individual deposits could not be reported.

Mercury is currently being recovered in a limited number of areas around the world. Approximately 57 pct of the total recoverable mercury at the demonstrated level is derived from six deposits that were producing at the time of this study. Much of the mercury currently being recovered is produced from the Almaden district in Spain. In 1983, Spain produced 43 pct of the total mercury for market economy countries, or 23 pct of the world's total mercury (*12*). Other currently producing market economy countries that are included in this study are Algeria, Turkey, and the United States.

Demonstrated resources from nonproducing deposits make up 43 pct of the total recoverable resource available from market economy countries. Much of the mercury resource recoverable from nonproducing deposits occurs in Italy; remaining resource material is available from Canada, the Philippines, Turkey, and the United States. Italian deposits of the Monte Amiata district are the source for 38 pct of the total recoverable mercury from market economy countries and have the potential for supplying 89 pct of the recoverable mercury from market economy countries not currently producing.

While this study evaluates demonstrated resources of known areas, additional mercury potential exists in areas with resource potential currently at the identified level. As these occurrences are further explored and resources upgraded to the demonstrated level, the quantity of available mercury could be increased. Approximately 17 million flasks of world mercury are reported to exist at the identified level (*12*).

DOMESTIC RESOURCES

Only 4 pct of the total demonstrated mercury resources can be recovered from domestic deposits. The United States

Table 3.—Demonstrated mercury resources as of January 1984

Country	Number of deposits	In situ: Hg grade, pct	In situ: Ore, 10^3 mt	Hg, 10^3 flasks: Contained	Hg, 10^3 flasks: Recoverable
Algeria	2	1.00	356	103.5	94.3
Italy	2	.56	12,248	2,006.9	1,752.2
Turkey	4	.33	2,053	195.3	158.3
United States	4	.27	2,520	199.9	161.4
Other[1]	3	1.29	7,410	2,766.5	2,401.8
Total or average[2]	15	.74	24,587	5,272.1	4,568.0
Producers	6	1.34	7,703	3,005.4	2,608.0
Nonproducers	9	.46	16,884	2,266.7	1,960.0

[1]Other includes Canada, Philippines, and Spain. Owing to proprietary considerations, these countries could not be treated separately.
[2]Computations using tabulated numbers may vary from reported values, owing to individual rounding.

produced only 13 pct of the world's primary mercury in 1983 (24 pct from market economy countries) (*12*). Domestic ore is of a much lower grade than ore produced throughout the world. While the weighted average ore grade for all market economy countries is 0.74 pct Hg, domestic ores have a weighted average grade of 0.27 pct Hg. The estimated ore grade of domestic producers is approximately one-third the grade for all world producers included in this study.

The number of producing domestic mercury operations has decreased dramatically in recent years. There were 109 active mercury mines in 1969, 24 in 1973, and only 1 in 1984 (*6, 12*). The bulk of domestic mercury production comes from the McDermitt facility in northern Nevada; a small amount of mercury is recovered from the Carlin and Pinson Mines in Nevada as a byproduct of gold refining. At present, mercury produced from secondary sources makes up 36 pct of total domestic mercury production (*12*).

Demonstrated resources at the McDermitt operation, 1.1 million mt at 0.438 pct Hg (*10*), constitute 44 pct of the total domestic resource tonnage. The deposit, however, contains approximately 74 pct of the current total recoverable mercury from domestic sources. The ore grade is significantly higher and ore occurs at a much shallower depth than in most other domestic deposits; consequently, it is not surprising that this deposit can sustain production while economic conditions prohibit production from other domestic deposits.

Regions with significant demonstrated resource potential include California, Nevada, and Texas. Traditionally, the California deposits were major producers. With the discovery of the McDermitt deposit in the 1970's and changing economic conditions, Nevada has recently surpassed California in mercury potential. Figure 7 gives the mercury resource distribution by State. Areas of significant mercury potential that merit investigation to further delineate resources are listed in appendix B.

Mercury in California occurs along the Coast Range in a southeast-trending belt extending up to 650 km long and 120 km wide (*11*). The higher grade areas have been mined extensively; consequently, remaining resources tend to be widely disseminated and low grade. The Gibraltar deposit in Santa Barbara County is the only California deposit considered to have substantial resources at the demonstrated level.

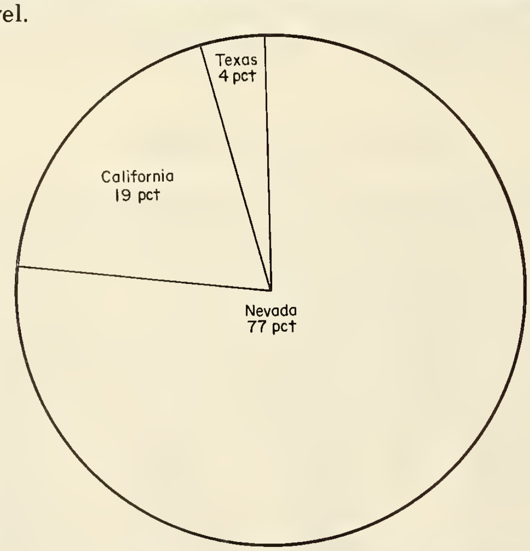

Figure 7.—Distribution of demonstrated domestic mercury resources.

The principal mercury-bearing areas in Nevada occur along a northerly trending belt in sedimentary and volcanic rocks in the west-central part of the State, extending south from McDermitt roughly 350 miles (*11*). Higher grade occurrences are found in the northern part of the belt. The B&B Mine is typical in that the low-grade ore is contained within highly disseminated, faulted volcanics of Tertiary age.

Mercury has been found in marine sediments of southwestern Texas. The region consists of numerous small occurrences and districts; mercury mining in the region ceased in 1960. The Study Butte Mine is the only remaining deposit with documented resources at the demonstrated level. Ore in this region is found at a greater depth than in Nevada and most California mines and would require underground mining methods.

The sustained low mercury price and demand in recent years have not encouraged new domestic mercury exploration. Most of the exploration took place in the 1950's when production was widespread and Government funding was available. Areas with significant identified resource potential have been found in Alaska, Arizona, California, Idaho, Nevada, Oregon, and Texas. Although most of the past production has occurred in California and Nevada, the areas of greatest future potential resources are likely to be Alaska, California, and Nevada, in areas where exploration has been limited. The Bureau estimates that approximately 490,000 flasks of contained mercury are available in the United States at the identified level (*2*).

Significant mercury is also available from other domestic sources. At the end of 1983, the National Defense Stockpile contained 178,315 flasks of primary mercury, reported industry stocks amounted to 31,518 flasks of primary mercury, and 35,305 flasks of secondary mercury are reportedly held in a Department of Energy stockpile (*2*). Since these sources of supply are not generally available on world markets, they were not included in the availability study; however, their importance should be noted in the overall domestic supply picture.

FOREIGN RESOURCES

Foreign mercury resource potential is limited to a few regions. Except for Mexico, where mercury resources consist of numerous small deposits, potential mercury resources are restricted to well-defined districts in Algeria, Canada, China, Italy, the Philippines, Spain, Turkey, the U.S.S.R., and Yugoslavia. Discussions in this study are limited to market economy countries whose resources are given in table 3.

The Almaden district in Spain has ore zones which are generally much larger, less irregular, and higher grade, as much as 20 pct Hg in some areas, than other districts. On an average basis, ore at Almaden is approximately 35 pct higher grade than the next higher grade deposit and 600 pct higher grade than an average U.S. mercury deposit. Approximately half of the total recoverable mercury available from market economy countries comes from the Almaden district. It is anticipated that the Almaden operation could continue to operate at current production levels for at least the next 100 yr should inferred resources of this deposit be proven, although production at much deeper levels may allow for a much greater mine life (*7*).

The Monte Amiata district in Italy has the second largest resource potential for market economy countries.

The district contains over 12 million mt of ore averaging 0.56 pct Hg, 38 pct of the recoverable mercury from market economy countries. All production in the district ceased in 1982 for economic reasons. Together, Spain and Italy make up the bulk of recoverable mercury for the evaluated market economy countries.

The mercury reserve potential of Turkey is similar to that of the United States. Ore occurs in several districts distributed across western Turkey, each district differing in host rock and mode of occurrence. Demonstrated resources for Turkey are 2.1 million mt of ore at 0.33 pct Hg, or roughly 3 pct of the evaluated resources based on recoverable mercury.

Canadian mercury potential is centered along the Pinchi fault zone in central British Columbia. The region contains over 1.2 million mt of demonstrated mercury ore at 0.29 pct Hg. Mining in the region first occurred during World War II; the Pinchi Lake facility operated briefly from 1968 to 1975.

Algerian mercury deposits have achieved a greater degree of importance as a result of recent discoveries and cessation of production from other deposits in recent years. Demonstrated resources are 356,000 mt at a relatively high average grade of 1.0 pct Hg. Although Algeria contains 2 pct of the total recoverable mercury resources of market economy countries, it supplied 11 pct of the total production from these countries in 1983 (*12*).

The ore grade from Philippine mercury deposits is marginal, and unless substantial mercury is discovered, it is unlikely that mercury from the Philippines will seriously influence mercury markets.

Little information is available about mercury resources in South America. Peru once produced substantial amounts of mercury from the Santa Bárbara Mine, but since its exhaustion, little mercury has been recovered from the surrounding area. Other South or Central American countries that have had minor production include Honduras, Colombia, Chile, and Venezuela. Total demonstrated resource potential from South American mercury deposits could amount to 30,000 flasks (*2*), but this amount could change should more exploration prove out additional mercury-rich areas. The resource figures for this region have not been included in this study because of their speculative nature.

Mercury resource potential from Mexico is reported to amount to 250,000 flasks (*12*), although as much as 1 million flasks of low-grade mercury may be available at costs exceeding $600 per flask. Mexican deposits are generally small, erratic, and highly variable in mode of occurrence and geologic association. Mexican statistics show minor mercury production since 1978. Currently Mexico is producing mercury as a byproduct or recovering it from small operations. All of the larger mercury operations have been dismantled. Because of the nature of the ore, individual Mexican deposits did not meet the deposit standards established for this evaluation, so were not included in this study. Reliable resource data are scarce, and most operating properties produce on a haphazard schedule based on market demand. Mexican mercury operations have responded rapidly to significant demand and price fluctuation in the past, so could possibly expand production if demand warranted such action.

Mercury resource potential from Yugoslavia is reported to amount to 500,000 flasks (*2*). Since available data are scarce, and confirmation of detailed economic data is not possible, resources from Yugoslavia have not been included in economic evaluations.

Several other areas have produced mercury as a byproduct from base metal refining. Approximately 5 pct of world mercury production in 1979 came from base metal refining operations in Australia, Czechoslovakia, Finland, and the Federal Republic of Germany (*6*); this potential resource has not been included in economic evaluations since the study is limited to primary resources.

Mercury production from centrally planned economy countries has recently become increasingly influential on world markets. In 1982, production occurred from mines in the U.S.S.R., China, and Czechoslovakia. While these resources are not included in the economic evaluations of this study, it should be noted that 46 pct of present production and 23 pct of estimated world resources originate from centrally planned economy countries (*12*).

EXTRACTION TECHNOLOGY

MINING

Mercury ore is mined by both surface (37 pct) and underground (63 pct) methods. The mode of occurrence of the mercury deposit determines the mining methods. The bulk of mercury ore is currently mined by conventional open pit mining methods. The ore and overburden are separately drilled, blasted, loaded, and hauled. Drilling is accomplished using track drills, equipped to bore holes 8.89 to 10.16 cm in diameter. ANFO is generally used as a blasting agent with a powder factor which could range from 0.1 to 2.4 kg of explosive per ton of material blasted. Broken ore is loaded by shovels and front-end loaders and is hauled by truck and rail to the beneficiation plant or to an onsite crusher.

The McDermitt Mine in Nevada is the only producing domestic mercury mine. It is presently the largest surface mercury mine in the market economy countries. Mining at McDermitt is relatively easy and somewhat atypical of the mercury industry. Blasting is required only in the highly siliceous opalite rock which underlies the mercury ore. The ore, a relatively unconsolidated mixture of lacustrine sediments and volcanic tuffs, is mined by scrapers.

Various underground mining methods are currently being conducted by the mercury industry; however, narrow-vein mining methods predominate, with cut-and-ill mining the most commonly used. Vertical crater retreat (VCR) mining, a relatively new mining method that has proven much more economical than cut-and-fill, is gradually becoming the primary method.

All underground mercury mines utilize conventional drilling, blasting, loading, and hauling. Drilling is done by jumbo drills in the larger mines and by handheld jackleg drills in the smaller. Mines employing the VCR method use down-hole drills. For the most part, ANFO is the blasting agent; powder factors could range from 0.2 to 0.5 kg of blasting agent per ton of ore. Broken ore is then loaded by mucking machines, slushers, or manually, and hauled by various means out of the mine.

The Antigua Mine, part of the Almaden operations of

Spain, is presently the largest underground mine in the market economy countries. The VCR mining method is replacing cut-and-fill methods at this operation.

BENEFICIATION

In general, beneficiation of mercury ore begins with crushing and screening. Mercury-bearing ore crushes more readily than barren rock; therefore, a crude separation of ore and barren rock is conducted by screening. Primary crushing is done by jaw crushers; screening, by grizzlies. In recent years, this first step in the beneficiation process has moved from the beneficiation facility to the mine site. A typical flowsheet for the mercury beneficiation process is shown in figure 8. Efficient mercury recovery can exceed 95 pct.

Secondary crushing and screening is accomplished by gyratory cone crushers and scalping screens. Ore is reduced in size from 7.62 cm to minus 1.91 cm. This final size has been found to be optimal for the subsequent roasting step.

In some operations mercury ore is further upgraded before roasting. Under these circumstances, ore is further reduced in size by use of rod mills, ball mills, or semiautogenous mills. Ore is then concentrated by flotation, jigging, and tabling. Flotation has been proven to be the most successful concentrating method, producing concentrates from 25 to 75 pct and recovering almost 90 pct of the mercury. This upgrading process has resulted in improved efficiency and considerable energy savings in the subsequent roasting step.

Roasting is essentially a distillation process and consists of heating the concentrate followed by condensation of the mercury vapor. Either mechanical furnaces or retorts are used in roasting. Mechanical furnaces include both multiple-hearth furnaces and rotary furnaces. Concentrate is fed continuously in furnaces; and temperature for volatizing is set at 746° C. Both types of furnaces exhibit advantages and disadvantages; the multiple hearth is more capital intensive than the rotary but much more energy efficient.

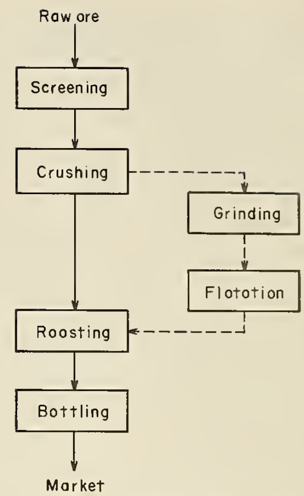

Figure 8.—Flowsheet of typical mercury beneficiation process.

Gases from furnacing are passed through dust collectors. Dust is collected and further processed, and the dust-free gas is directed to the condenser system, where mercury vapor is condensed and collected. The condenser system consists of a series of cast iron or stainless steel pipes; mercury is collected at the bottom of pipes in launders or buckets.

Retorts are also used in roasting mercury ore. They are relatively inexpensive compared to the mechanized roasters but exhibit several disadvantages: mercury ore must be batch loaded, manually charged, and discharged. In addition, they are relatively small in capacity.

ENVIRONMENTAL CONSIDERATIONS

While mercury ores and to a large extent metallic mercury are not particularly toxic to plants and animals, mercury vapor and many of its compounds are poisonous to all forms of life. Therefore, care must be taken to avoid contamination of the environment when mining and processing mercury ore, and stringent precautions must be undertaken to avoid the poisoning of personnel affiliated with the mercury operation.

Mercury poisoning, mercurialism, begins with the absorption, ingestion, or inhalation of large quantities of mercury vapor over a short period of time (acute poisoning) or smaller quantities of mercury vapor over longer periods (chronic poisoning). Symptoms of acute poisoning include metallic taste, abdominal pain, vomiting, headaches, diarrhea, and cardial weakness. Chronic poisoning develops gradually and often without conspicuous warning signs. Early symptoms may include general weakness, inflammation of the mouth, loosening of the teeth, excessive salivation, emotional instability, and body tremors.

Personnel associated with mercury operations processing toxic mercury compounds are most often the victim of chronic mercury poisoning. Many years ago, prisoners and slaves were used to mine and process mercury ore, with little regard to their health. Today, worker safety is a prime consideration. Mercury vapor emissions from the processing furnaces or retorts have been radically reduced. Educating workers regarding mercury poisoning and its causes has had a profound positive impact. Direct exposure to high concentrations of mercury vapor is avoided. Safety gear, such as helmets, respirators, gloves, and rubber boots, is worn; the importance of hygiene is accented. Regularly scheduled physical examinations are required.

Domestic mercury workers are protected by Mine Safety and Health Administration and Occupational Safety and Health Administration regulations. MSHA regulations limit mercury exposure to a maximum concentration of 50 $\mu g/m^3$ or 1 mg/10 m^3 in an average 8-h period (*6*). The Bureau has been active in research to improve the health and safety of mercury workers. The Environmental Protection Agency has issued regulations on the discharge of mill waste water from the ore and milling facilities under the Clean Water Act, December 3, 1982. Effluent limitations under this act are set at 0.002 mg/L for any given day and at 0.001 mg/L as an average daily value for 30 consecutive days.

Foreign environmental regulations are generally less stringent than domestic regulations. However, a unique rule is applied to mining and processing at the Almaden operations in Spain, where employees are scheduled to work only two or three 6-h shifts per week.

CAPITAL AND OPERATING COSTS

Capital and operating costs in this study have been developed based on actual data or estimated from best available sources. The average total production cost estimated for each deposit analyzed includes mining and concentrating costs, transportation costs to the processing facilities, capital recovery, taxes, and profit. These costs often vary greatly depending on such factors as size of operation, mining method, deposit location, stripping ratio, depth of ore body, grade of ore, processing losses, energy and labor costs, environmental regulations, and tax structure.

Capital costs presented in this section reflect nonproducing operations only. These costs reflect either the cost required to develop the operation, construct all facilities, and begin production or, as in most cases, the additional capital required to recondition preexisting facilities and construct any additional facilities to enable the mine to resume operations.

Operating costs are weighted averages reported in terms of cost per recoverable ton of ore and cost per flask of recoverable mercury over the future life of the operation.

CAPITAL COSTS

Capital costs include costs for exploration, development, mine and mill plant and equipment, working capital, and infrastructure, where required. Relatively simple processing steps are required to obtain prime virgin mercury. Any smelting and/or refining operations that may be required have either been incorporated into the mill capital cost or been treated as a mill custom charge included in the mill operating cost.

Most deposits included in this study either are currently producing or have produced within the past 10 yr. Many nonproducing operations considered in this study have existing facilities that only need to be rehabilitated or modernized in order to resume production. Capital costs for these operations include all costs necessary to rehabilitate the facilities to enable production to begin utilizing current mining and beneficiation practices. Capital costs for producing operations are not included because most have been operating for many years and a large portion of the initial investment has been depreciated. Capital expenses for these operations are limited to replacement or expansion of facilities.

Analyses indicate that capital costs required to bring the principal nonproducing mercury deposits back into production range from $900,000 to $10.5 million, or from $15 to $140 per metric ton of ore mined. Larger deposits require larger capital expenditures but were lower cost operations on a per ton basis.

Modernization capital costs vary considerably from country to country. Capital costs in the United States range from about $2,900,000 for small operations to $10,500,000 for larger operations. U.S. costs were the highest on a cost per ton basis, ranging from $40 to $140 per metric ton of ore mined on an annual basis. Costs of rehabilitating Turkish mines were also high on a cost per ton of ore basis. Costs ranging from $900,000 to $2.3 million were required for small operations producing 15,000 to 50,000 mt of ore annually. Capital costs in Canada and Italy of $20 to $40 per metric ton of ore are comparable, but modernization costs for the higher production (340,000 to 350,000 mt) Canadian operation are $7.6 million to $8.4 million, while smaller (20,000 to 230,000 mt) Italian properties have capital costs ranging from $1 million to $5.4 million. Medium-size operations in the Philippines have the lowest capital cost on a per ton of ore basis ($15 to $20). Total costs range from $2.8 million to $3.2 million.

Mine capital costs range from 44 to 93 pct of the total capital cost. The highest mine costs were found for mercury deposits in Canada, the United States, and Italy, where the underground mining methods to be employed are very capital intensive.

Mill capital costs range from 7 to 56 pct of the total capital cost. Mill costs are low because many of the deposits under consideration have existing processing facilities requiring only minor modifications to bring the facility back on-line.

OPERATING COSTS

Summaries of estimated operating costs for principal mercury deposits are given in table 4 in terms of cost per recoverable ton of ore and in table 5 in terms of cost per recoverable flask. For each producing or nonproducing country considered in this study, a range of costs is given for each operating cost category. Individual deposit costs, while included within the reported cost ranges, are withheld to preserve proprietary data.

Operating costs include the costs of mining, beneficiation, and all transportation up to the last stage of processing prior to market. Any smelting or refining, if required, has been included in the mill operating cost. Mine and mill operating costs include all costs for labor, energy, and supplies, and indirect costs of administration, maintenance, overhead, etc. All other miscellaneous costs have been included in the "other" category. This includes recovery of capital, 15-pct return on investment, taxes (property, severance, State, and Federal), and any additional transportation charges (where applicable). No byproduct revenues have been included in this analysis, since mining operations commonly produce mercury as a single marketable commodity without any byproducts. Total cost reflects the sum of the mine, mill, and other categories and can be compared to a long-term market price which indicates which properties have sufficient return on capital investment to provide an incentive to produce. If an operation showed costs that consistently were higher than the market price, the company might consider a temporary cessation of operations until market conditions improve. State owned or controlled operations may continue producing even under a nonprofitable situation if the resulting losses are less than those incurred if the operations were closed. A closure may require payment of unemployment, welfare, or loss of training benefits. Governments may also need sales revenues generated by the operation to import other needed materials into the country.

Mining costs on a per ton of ore basis vary from 10 to 75 pct of the total operating cost for evaluated mercury deposits. The highest mining costs occur for the Italian mercury deposits where ore is recovered by expensive underground methods; the lowest costs occur in surface mining operations in the United States and Turkey, where mining occurs at shallow depths and requires minimal blasting. For those deposits studied, mining costs average 25 pct of the total operating cost for surface mines and 46 pct for

Table 4.—Estimated operating costs for principal mercury deposits, per metric ton of ore

Status and location	Type of mining[1]	Annual production rate, 10^3 mt	Cost range (January 1984 $)[2] Mine	Mill	Other[3]	Total
Producer:						
United States	S	250 - 300	$5 - $10	$5 - $10	$5 - $10	$20 - $30
Turkey	U	40 - 50	20 - 30	10 - 20	1 - 10	40 - 50
Spain	S-U	150 - 200	10 - 20	30 - 40	10 - 20	50 - 60
Algeria	S	20 - 40	20 - 40	30 - 40	10 - 30	80 - 90
Weighted average	—	94	14	18	11	43
Nonproducer:						
Philippines	S	160 - 170	5 - 10	10 - 20	5 - 10	20 - 30
Turkey	S-U	15 - 50	1 - 20	10 - 20	10 - 40	20 - 70
Canada	S-U	340 - 350	10 - 20	5 - 10	10 - 20	30 - 40
United States	S-U	20 - 130	5 - 60	5 - 40	10 - 70	30 - 170
Italy	U	20 - 230	40 - 60	10 - 20	5 - 20	70 - 80
Weighted average	—	118	25	12	14	51

[1]S = surface; U = underground.
[2]Estimated costs fall within the given range; range limits may not reflect specific actual costs.
[3]"Other" cost category includes costs for capital recovery, taxes, and profit to achieve a 15-pct DCFROR.

Table 5.—Estimated operating costs for principal mercury deposits, per flask of recoverable mercury

Status and location	Type of mining[1]	Annual production rate, 10^3 mt	Cost range (January 1984 $)[2] Mine	Mill	Other[3]	Total
Producer:						
United States	S	250 - 300	$80 - $90	$80 - $90	$70 - $80	$240 - $250
Turkey	U	40 - 50	230 - 280	160 - 190	40 - 60	430 - 520
Spain	S-U	150 - 200	20 - 30	60 - 70	30 - 40	120 - 130
Algeria	S	20 - 40	80 - 220	90 - 250	70 - 150	240 - 600
Weighted average	—	94	97	99	62	258
Nonproducer:						
Philippines	S	160 - 170	230 - 250	460 - 470	410 - 420	1,100 - 1,200
Turkey	S-U	15 - 50	150 - 230	220 - 370	450 - 480	900 - 1,000
Canada	S-U	340 - 350	270 - 280	110 - 120	170 - 180	500 - 600
United States	S-U	20 - 130	360 - 570	200 - 1,570	330 - 2,700	900 - 4,700
Italy	U	20 - 230	200 - 450	60 - 100	50 - 60	300 - 600
Weighted average	—	118	329	309	419	1,057

[1]S = surface; U = underground.
[2]Actual costs fall within the given range; range limits may not reflect specific actual costs.
[3]"Other" cost category includes costs for capital recovery, taxes, and profit to achieve a 15-pct DCFROR.

underground mines. The average mining cost is $14 per metric ton of ore for surface operations and $31 per metric ton of ore for underground operations.

Milling costs on a per ton ore basis range from 16 to 53 pct of the total operating cost for mercury deposits considered in this study. Generally, beneficiation techniques are similar for all operations considered; this can be seen from the relatively low degree of variability of milling costs (in comparison to mining costs). The highest milling costs occur for Algerian deposits which operate at a comparatively low production rate; low milling costs are found in deposits with much higher production rates such as the major deposits in the United States, Canada, and Italy. The average milling cost is $19 per metric ton of ore for the mercury deposits evaluated in this study.

The total operating cost for producing mines ranges from $20 to $30 per metric ton of ore in the United States to $80 to $90 per metric ton of ore for Algerian mercury operations (table 4). The average total operating cost for a producing mine is $57 per metric ton of ore. On a cost per flask of product basis, operating costs for producing mines range from $120 to $130 per flask in Spain to $240 to $600 in Algeria (table 5). The average total operating cost for a producing deposit is $360 per flask of mercury. While the U.S. mercury deposit has the lowest operating cost range on a per ton basis, it does not have the lowest cost when measured per flask of recoverable mercury (table 5), which is influenced by the grade of the mercury ore. On a cost per ton of product (flasks of recoverable mercury) basis, the high-grade Spanish ores have the lowest total operating cost when compared to the lower grade ores of the United States, which have higher operating costs. Algerian deposits appear to have the highest operating costs owing to a combination of low production rate, lower grade, and higher energy and labor costs, but costs vary widely due primarily to the large grade variation of Algerian deposits.

The total operating cost for nonproducing deposits ranges from about $20 per metric ton of ore for deposits in the Philippines to as much as $170 per metric ton for some U.S. deposits. The average total production cost estimated for a nonproducing deposit is $65 per metric ton of ore, or $1,296 per flask of mercury. A much wider cost range exists for nonproducing deposits on a cost per flask of mercury basis. Italian mercury deposits have costs ranging from $300 to $600 per flask, while very low-grade mercury deposits in the United States have costs that reach $4,700 per flask. At a January 1984 mercury price of approximately $300 per flask, it is apparent that a much higher mercury price will be required before many of these nonproducing operations could become profitable using existing technology.

MERCURY AVAILABILITY

The potentially recoverable mercury from market economy countries is illustrated by availability curves and tables. Of the 15 properties analyzed in this study, one property containing approximately 6,000 flasks of mercury has been excluded because of unusually high costs of production. After cost and quantity data were determined for each property, total and annual availability curves were constructed to indicate recoverable resource availability. These analyses are based on the following assumptions:

1. No definite startup dates were known for nonproducing deposits; preproduction development work for each deposit was proposed to begin in year "N"
2. Time lags related to permitting, environmental impact statements, and other possible delays affecting production are minimized.
3. Each operation will produce at its full design capacity.
4. Competition and demand conditions are such that each operation will be able to sell all of its output at its anticipated total production cost.
5. Total cost, also called commodity or incentive price, is defined as the average total cost of production for the commodity and covers all production costs including a 15-pct rate of return on invested capital.
6. Current tax structures and 100-pct equity were used in all simulations.

TOTAL AVAILABILITY

Table 6 reports the total availability of mercury from evaluated deposits in market economy countries. The January 1984 market price for prime virgin mercury at New York was approximately $300. At a total production cost equivalent to this price, approximately 2.5 million flasks of mercury are available, all from currently producing deposits. When the total production cost rises from $300 to $600 per flask, the amount of mercury available increases from 2.5 million flasks to 4.5 million flasks. The total recoverable mercury from all evaluated properties, 4.6 million flasks, is available at costs less than $1,700.

Table 6.—Total resource availability

Status	Cost range per flask	Total recoverable Hg, 10^3 flasks
Producers	$300	2,454
	600	2,607
Nonproducers	450	53
	600	1,882
	1,000	1,930
	1,700	1,954
Total	300	2,454
	600	4,489
	1,000	4,537
	1,700	4,561

Table 6 indicates that 2.6 million flasks of mercury are recoverable from producing properties at production costs ranging up to $600 per flask. Approximately 2 million flasks of mercury are recoverable from currently nonproducing properties at production costs ranging from $450 to $1,700 per flask.

ANNUAL AVAILABILITY

Analyses were performed to estimate the potential annual production capabilities of producing and nonproducing deposits. Production potential for nonproducing deposits was estimated based upon deposit size (demonstrated resources), past production history, and capacities of similar producing operations. Estimates of production potential at the given capacity levels for the next 15 yr are provided. Based upon these assumptions, an analysis of annual mercury availability is presented below.

Figure 9 shows annual mercury availability from producing deposits. At a production cost of $600 per flask, approximately 126,000 flasks of mercury are annually available between the years 1984 and 1988. This compares

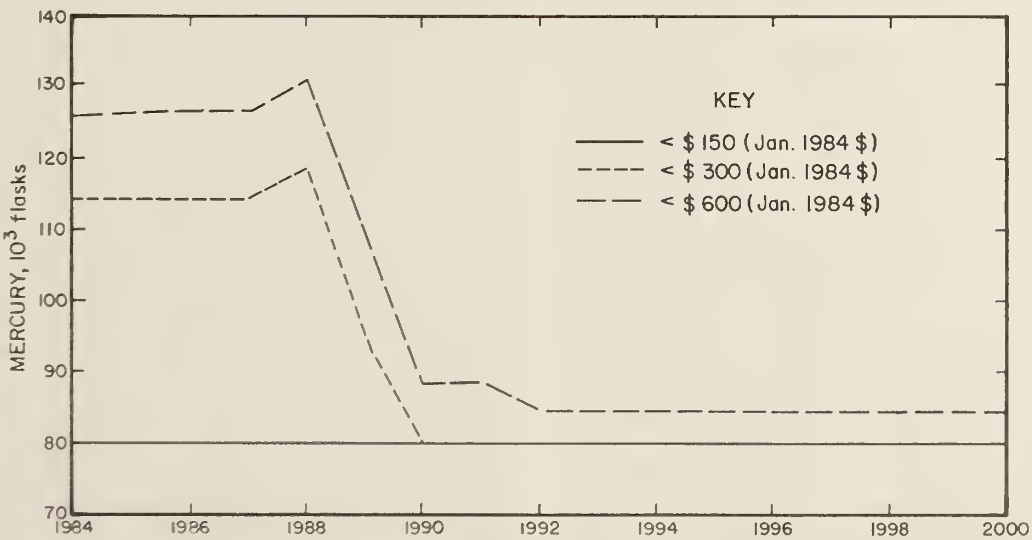

Figure 9.—Annual availability from producing deposits at various prices.

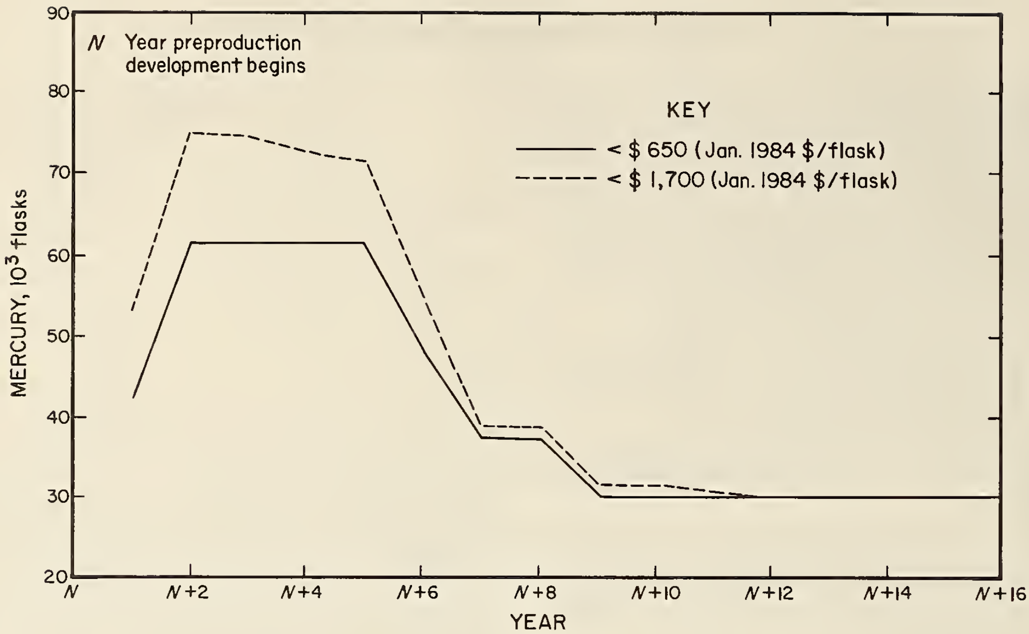

Figure 10.—Annual availability from nonproducing deposits at various prices.

with 103,500 flasks of mercury produced from market economy countries in 1983. By the end of 1992, production would decrease to 85,000 flasks of mercury per year, if resources from deposits having total production costs between $500 to $600 per flask are depleted by the end of that year. This decrease may be offset if resources currently considered inferred are further explored and proven, thereby increasing the demonstrated reserve base. From 1992 through 2000, mercury availability remains stable at 85,000 flasks per year.

Similarly, approximately 114,000 flasks of mercury are available between 1984 and 1988 at a production cost of less than $300 per flask. This is sufficient to meet the 1983 production rate of 103,500 flasks per year from market economy countries. Availability goes down to 80,000 flasks per year by 1990 and remains at this level until at least 2000. Much of this decrease in primary mercury availability could be offset by increased sales from stockpiles or use of mercury from secondary sources.

At the present mercury market price, deposits evaluated in this study supply approximately 59 pct of current world production of primary mercury. The remainder is supplied by centrally planned economy countries or countries with small production not evaluated in this study. In 1990, deposits considered in this study would only be able to provide 34 pct of probable demand of 233,000 flasks (table 1). By 2000, only 27 pct of the probable demand (295,000 flasks) would be available from deposits with total production costs less than $300 per flask. Additional mercury resources would need to be defined at much higher production costs to meet the anticipated demand in 2000.

Generally, nonproducing deposits have much higher production costs than producing properties. This is due in part to the higher investments that are required and to the generally lower ore grade. The average ore grade of nonproducing deposits is approximately one third of that for producing deposits. Construction of annual availability curves for these nonproducing properties is based on the assumption that preproduction development would begin in the year *N*. Past experience indicates that 1 or 2 yr would be required from the year development begins before any production could occur. Annual availability of mercury from nonproducing deposits is shown in figure 10. No mercury from these deposits is available at the current market price of approximately $300 per flask, although one property has a production cost of less than $350 per flask and has the potential of recovering 7,200 flasks per year through year *N*+7 should market conditions merit its reopening.

Most of the mercury from nonproducers can be recovered at costs ranging from $500 to $1,000 per flask. Approximately 61,000 flasks become available in years *N*+2 through *N*+5 at a production cost of less than $650 per flask, while a total of 69,000 flasks is available at costs less than $1,000 per flask for the same interval. Within the same period, for costs ranging from $1,000 to $1,700 per flask, an additional 6,000 flasks become available for a total of 75,000 flasks at a cost of less than $1,700 per flask.

Mercury available from nonproducing deposits decreases rapidly from years *N*+6 through *N*+9. At this point, only 30,000 flasks of mercury are available at costs less than $650 per flask. This quantity continues to be available until *N*+15, the last year of the analysis period.

To meet anticipated future demand, additional mercury production is required to supplement those properties currently producing. Assuming a demand of 233,000 flasks in 1990, producing operations could potentially supply 36 pct at costs up to $600 per flask; deposits not currently producing could supply an additional 30 pct at costs up to $1,000 per flask. The remaining one-third would have to be supplied from either centrally planned economy countries, from Government or industry stockpiles, or from recycled mercury.

Actual annual availability could vary from anticipated availability as market conditions change. Factors that would affect such a change include varied production of existing mines, nonproducing deposits coming into production, discovery of additional deposits, and reclassification of inferred resources as demonstrated.

FACTORS AFFECTING AVAILABILITY

Factors that could affect mercury availability are inflation, labor, and energy costs. These factors were analyzed to determine the magnitude of effect on mercury availability. Based upon these analyses, the relative effect was very small.

The effect of inflation on mercury availability is negligible. A 25-pct increase in capital costs as a result of inflation results in a decrease in available mercury of 0.9 pct; a 50-pct increase results in a 2.4-pct decrease in available mercury at a cost of $1,000 per flask. At a total production cost of $600 per flask, a 10- or 15-pct increase in operating cost results in a decrease in availability of 22,000 flasks from a base of 2.6 million flasks; a 25-pct increase results in a decrease of 53,000 flasks at $600 per flask.

The effects of changes in labor or energy costs on mercury availability were also found to be negligible. At $600 per flask, mercury availability decreased 0.8 pct for both 10- and 15-pct increases in labor costs. The effects of energy increases on mercury availability were similar to those for labor.

Stockpiled and secondary mercury sources should also be considered in mercury availability discussions. Owing to mercury's limited sources of supply, many countries have considerable stockpiles of mercury, which may be used to meet internal mercury demand requirements should internal supply or import problems arise. In the United States, for example, 12,786 flasks of mercury were imported in 1983 while the U.S. stockpile contained 178,315 flasks (*2*). In the event of a total disruption of all imported sources of mercury, the stockpile, if maintained at the 1983 level, represents a potential 14 yr supply at 1983 levels to supplement domestic production. Currently, efforts are being made to reduce the mercury stockpile inventory to 10,500 flasks, an effort that influences both short- and long-term domestic supply patterns.

Primary mercury price patterns also may significantly affect mercury recovery from secondary mercury sources (recycling and byproduct recovery). A significant increase in primary mercury price could result in increased recovery of mercury from secondary and byproduct sources. Current trends indicate, however, that the relative proportions of mercury recovery from primary and secondary sources should be relatively stable, barring any major changes in recovery technology or mercury prices.

CONCLUSIONS

There has been little change in mercury mining and processing technology in recent years. A greater change has occurred in mercury use patterns where technological changes in mercury battery design, more efficient chlor-alkali cells, and improvements in the substitute diaphragm cell have begun to reduce primary mercury consumption. Environmental concerns have provided impetus for more efficient recycling practices. Recycled mercury will undoubtedly make up a significant portion of mercury supply in the future.

The mercury industry appears to be stabilizing after a period of low demand and depressed market price brought about in part by increased environmental concerns and use of substitutes. Although prime virgin mercury consumption appears to be decreasing slightly, there are few indications that producers are curtailing output. Excess production from principal market economy countries is being stockpiled; most production from centrally planned economy countries is being consumed internally. At present, the $300 per flask price appears stable. Production is reduced or curtailed for those operations that repeatedly incur costs above this level; a market price well above this level would encourage increased mercury production.

Demonstrated in situ resources of mercury from market economy countries amount to approximately 25 million tons of ore from which 4.6 million flasks of mercury are potentially recoverable utilizing present technology. In light of prevailing economic conditions, it is estimated that these demonstrated resources could supply mercury at least until 2000 at proposed production levels. Mercury from producing properties operating at costs less than $600 per flask would be sufficient to meet market economy production needs at current production rates until 1988. Mercury availability could be greatly increased as known mercury occurrences, with identified tonnages containing over 17 million flasks, are further explored and resources upgraded to the demonstrated level. Countries with the greatest future mercury potential include Spain, China, the U.S.S.R., Yugoslavia, Italy, and the United States (primarily California, Nevada, and Alaska).

Domestic mercury requirements will become much more dependent on foreign sources when the only domestic primary mercury producer exhausts its reserves within the next 5 to 8 yr. Demonstrated domestic resources are not sufficient to meet anticipated domestic demand; current production levels could only be maintained if (1) exploration work delineated additional demonstrated resources, (2) higher market price justified mining of low-grade, high-cost deposits, or (3) high environmental pollution control costs could be acceptable. It is unlikely that mercury prices will reach high enough levels to justify reopening or development of other domestic resources in the near future.

Foreign dependency could be lessened through the use of mercury from Government and industry stockpiles and secondary sources.

Approximately 2.5 million flasks, or 54 pct of the total available mercury, as determined in this study, could be economically recovered at the January 1984 market price of approximately $300 per flask from operating mines in Spain, Algeria, and the United States. If mercury costs reach $600 per flask, 96 pct of the total available mercury, or an additional 2 million flasks, would become available from producing and nonproducing deposits.

Based upon forecast demand levels, assuming an annual growth rate of 1.4 pct, mercury from market economy countries recoverable at a total production cost of $300 per flask would supply only 33 pct of total world demand in 1990. Market economy countries could supply only 29 pct of anticipated world demand by 2000. To meet demand requirements, additional properties would need to come online to supplement producers at higher mercury costs, or a greater percentage of mercury could be purchased from centrally planned economy countries. Mercury production from these countries has increased in recent years. These demand projections could change significantly, however, if the projected growth rate does not come about owing to a decrease in mercury demand.

REFERENCES

1. Bailey, E. H., A. L. Clark, and R. M. Smith. Mercury. Ch. in United States Mineral Resources. U.S. Geol. Surv. Prof. Paper 820, 1973, pp. 401-414.

2. Carrico, L. C. Mercury. Ch. in Mineral Facts and Problems, 1985 edition. BuMines preprint B 675, 1985, 10 pp.

3. Clement, G. K., Jr., R. L. Miller, P. A. Seibert, L. Avery, and H. Bennett. Capital and Operating Cost Estimating System Manual for Mining and Beneficiation of Metallic and Nonmetallic Minerals Except Fossil Fuels in the United States and Canada. BuMines Spec. Publ., 1980, 149 pp.

4. Davidoff, R. L. Supply Analysis Model (SAM): A Minerals Availability System Methodology. BuMines IC 8820, 1979, 45 pp.

5. Davis, F. F., and E. H. Bailey. Mercury. Ch. in Mineral and Water Resources of California. CA Div. Mines and Geol. Bull. 191, 1966, pp. 247-254.

6. Drake, H. J. Mercury. Ch. in Mineral Facts and Problems, 1980 Edition. BuMines B 671, 1981, pp. 563-574.

7. Mining Magazine (London). Almaden - World's Largest Mercury Mine. V. 118, No. 2, 1968, pp. 80-91.

8. ______. McDermitt Mine - the U.S.A.'s Largest Producer of Mercury. V. 146, No. 7, 1982, p.261.

9. Pennington, J. W. Mercury. A Materials Survey. BuMines IC 7941, 1959, 92 pp.

10. Placer Development Limited (British Columbia, Canada). 1983 Annual Report. p. 29.

11. U.S. Bureau of Mines. Mercury Potential of the United States. BuMines IC 8252, 1965, 376 pp.

12. ______. Mineral Commodity Summaries 1984. Mercury. January 1984, pp. 98-99.

13. U.S. Geological Survey. Principles of a Resource/Reserve Classification for Minerals. U.S. Geol. Surv. Circ. 831, 1980, 5 pp.

APPENDIX A

Domestic deposits considered for evaluation but not included in this study since deposit selection criteria were not met are California—Buena Vista, Gambonini, Guadalupe, Knoxville, Mt. Jackson, and New Almaden; Texas—Fresno.

APPENDIX B

Numerous areas have either recovered mercury in the past or are reported to contain mercury. Although numerous occurrences are documented, deposits with demonstrated resources are rare. Domestic areas with significant mercury potential (*11*) that require additional exploration work to delineate resources are—

Alaska: Bristol Bay region, Kuskokwim River region, Seward Peninsula region, Yukon River region.

California: Adelaide district, Altoona district, Cambria-Oceanic district, Clear Lake district, East Mayacmas district, Guerneville district, Knoxville district, New Almaden district, New Idria district, Petaluma district, Stayton district, Sulphur Springs Mountain district, West Mayacmas district, Wilbur Springs district.

Idaho: Valley County district, Washington County district.

Nevada: Antelope Springs district, Fish Lake Valley district, Goldbanks district, Ivanhoe district, Opalite district, Union district.

Oregon: Crook County district, Lake County district.

Texas: Buena Suerte district, Terlingua district.

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